This document contains excerpts from the X-34 Independent Assessment Report (title page shown below). Only those sections which relate to the PBMA element **Hardware Design** are displayed.

The complete report is available through the PBMA web site, Program Profile tab.

X[34]

Safety & Mission Assurance Review

NASA
Office of Safety & Mission Assurance

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3.2. Design-Related SMA Processes

3.2.1 Material Allowables

The X-34 vehicle is largely a composite material construction. Three composite vendors support the program: 1) Vermont Composites (fuselage), 2) Aurora Flight Sciences (wing), and 3) R-Cubed (control surfaces). NASA Report 4078, "Composite Spacecraft Structural Design Guide" was employed by the X-34 design team.

The traditional "A-basis" allowable criteria requires that 99% of the specimens in a production lot (or from a stable and controlled process) exceed the structural performance A-basis limit. This requirement must be demonstrated through a statistical sampling procedure necessary to achieve a 95% level of confidence. Most aerospace metallic structural components (such as 7000 series aluminum) are well-characterized and A-basis values are available, and can be found in Mil Handbook 5F. In the case of composite material where not as much statistical data is available, "B-basis" criteria are employed. B-basis performance criteria are defined in terms of the performance level that 90% of the specimens will exceed, demonstrated with a 95% level of confidence. The X-34 uses A-basis allowables for all metallic components and B-basis allowables for all composite components.

3.2.2 Design Factors of Safety

Design limit load is the predicted worst case ground, flight, or recovery load including all uncertainties, specifically, variance in thermal, pressure, and flight loads. Design limit is determined by a 3-sigma high case derived from a Monte Carlo simulation of flight trajectories. Design yield load is design limit multiplied by yield factor of safety. Design ultimate load is design limit multiplied by ultimate factor of safety.

> Yield (or 1st ply failure for composites) Safety Factor = 1.25
> Ultimate Safety Factor = 1.5

Structural acceptance tests are conducted to design limit level. Protoflight testing is conducted to design yield level. These tests are repeated to Limit Levels to insure that the structure has not been damaged.

3.2.3 Computer Aided Design (CAD)

The X-34 Program uses the "Ideas Master Series" software for CAD. This design-tool developed by Structural Dynamics Research Corporation, provides full 3D modeling capability used for interference checking, and library storage of parts and assemblies. The system is accessible for all users. The system allows one-user modification of parts and notification of part and assembly changes. Ideas incorporates an integrated finite element stress analysis capability including composite laminate analysis. OSC employs this tool as a design environment and communication tool with vendors but stops short of the "paperless design" concept. Printed drawings are still used as the "design release" medium for all manufacturing activity. As discussed in other sections of this document, concurrent engineering is implemented in informal meetings as well as formal subsystem reviews.

3.2.4 Failure Modes, Effect & Criticality Analysis (FMECA) Process / FMEA

The conventional purpose of doing a Failure Mode Effects and Criticality Analysis (FMECA) is to assist and support the iteration of hardware and software design activity. After the design is baselined, the purpose of the FMECA and its derivative, the CIL, is to serve as a tool to aid program management in understanding and managing the risks inherent in the design. In addition, it documents those parameters which will assist in manufacturing process control, assembling interfaces, flight system operations, software development, and the test and evaluation of Government-Furnished-Equipment. The FMECA is not generated as a deliverable to the Government program office but is used by Orbital Science Corporation as an information tool to support the decisions made by the design, development, test and evaluation, and operation teams. The CIL is not generated for this program because the X-34 is a single string design for all areas except the Flight Termination System (FTS). The following table provides a synopsis of the current status of FMECA development on the X-34 program.

Main Propulsion System:	95% complete
Hydraulics	90% complete
Flight Termination System:	70% complete
Avionics	50% complete
Structures :	FMECA performed as part of the design and not formally documented

The FMECA is also employed (along with Hazard Analysis and Fault Tree Analysis) in developing the integrated (ground & flight) safety analyses contained in the ARAR Accident Risk Assessment Report.

3.2.5 Test and Verification

The X-34 design is verified by a series of material qualification tests at the laminate level to verification and proto-flight tests at the assembly level. Quality is assured at all levels of fabrication including certification of fiber properties, lot and batch testing of pre-preg material and witness coupon testing for each laminate cured. Acceptance tests are conducted for all components and assemblies. Figure 3.9 shows a typical design/test and verification process. Each structural element is tracked and indexed by load case and critical failure mode. For each element the verification method (analysis, handbook data, coupon test, element test, protoflight test) is identified along with applicable testing protocol definition. The flow diagram in Figure 3.10 shows the multi-level testing approach employed on the X-34 program for the case of a composite structural element, beginning at the fiber level and progressing to integrated structure testing.

Figure 3.9 Test and Verification Process

Structure Verification Matrix Example : Wing

Element	Sub-Element	Load Case	Failure Mode	Verification Method						Test Identification
Spar	Upper Cap	Pull-Up, Landing	Compression	A		CT		PT		MQT-1, WST-1,-2
	Lower Cap	Pull-Up, Landing	Tension	A		CT		PT		MQT-2, WST-1,-2
	Web	Pull-Up, Landing	In-Plane Shear	A		CT		PT		MQT-3, WST-1,-2
	Web Core	Pull-Up, Landing	Core Shear, Core Bond	A	HD		ET	PT		HCS-1,-2,-3
	Spar Skin	Pull-Up, Landing	Buckling	A				PT		WST-1,-2
Skin	Upper Skin	Pull-Up	Compression	A		CT		PT		MQT-1,-2,-3, WST-1
		Pull-Up	Buckling	A				PT		WST-1
		Max Torsion	Shear	A		CT		PT		WST-4
		Transonic Max Lift	Normal Pressure	A		CT		PT		MQT-1,-2,-3, WST-1
	Up Skin Core	Pull-Up, Max Lift	Core Shear, Core Bond	A	HD		ET			HCS-1,-2,-3
	Lower Skin	Pull-Up	Tension	A		CT		PT		MQT-1,-2,-3, WST-1
		2.5 psi Venting	Normal Pressure	A		CT		PT		MQT-1,-2,-3, WST-1
	Low Skin Core	Pull-Up, Max Lift	Core Shear, Core Bond	A	HD		ET			HCS-1,-2,-3
	Main Gear Door	2.5 psi Venting	Normal Pressure	A		CT		PT		MQT-1,-2,-3, WST-1
Ribs	Gear Rib	Main Gear Loads	Bearing, In-Plane Shea	A		CT	ET	PT		MQT-3, BJT-1, WST-2
		Gear Door Hinge Loads	Bearing, Bending	A			ET			BJT-1,-2
	Actuator Rib	Elevon Actuator Loads	Bearing, In-Plane Shea	A		CT	ET	PT		MQT-3, BJT-1, WST-3
Leading Edge	Slant Surface	Max Stag. Pressure	Normal Pressure (Push)	A		CT				MQT-4
		Tile Pull Test	Normal Pressure (Pull)	A		CT				MQT-4
Spar to Skin		Pull-Up, Max Sub Lift	Peel, Shear	A			ET	PT		AJT-1,-2,-3, WST-1
Spar Web to Spar		Pull-Up, Max Sub Lift	Peel, Shear	A			ET	PT		AJT-1,-2,-3, WST-1
Rib to Skin		Landing, Max Sub Lift	Peel, Shear	A			ET	PT		AJT-1,-2,-3, WST-2
Spar to Rib		All	Peel, Shear, Twist	A			ET	PT		AJT-1,-2,-3, WST-1,-2,-3
Wing Skin to Fuselage		Pull-Up, Landing	Shear, Bending	A			ET		VT	BJT-1,-2, SLT-1
Elevon to Spar		Max Deflection (+/-)	Shear, Bending	A		CT		PT		MQT-3,-4, WST-3

A = Analysis
HD = Handbook Data
CT = Coupon Test
ET = Element Test
AT = Comp. Acceptance Test
PT = Comp. Protoflight Test
QT = Comp. Qualification Test
VT = Vehicle Test

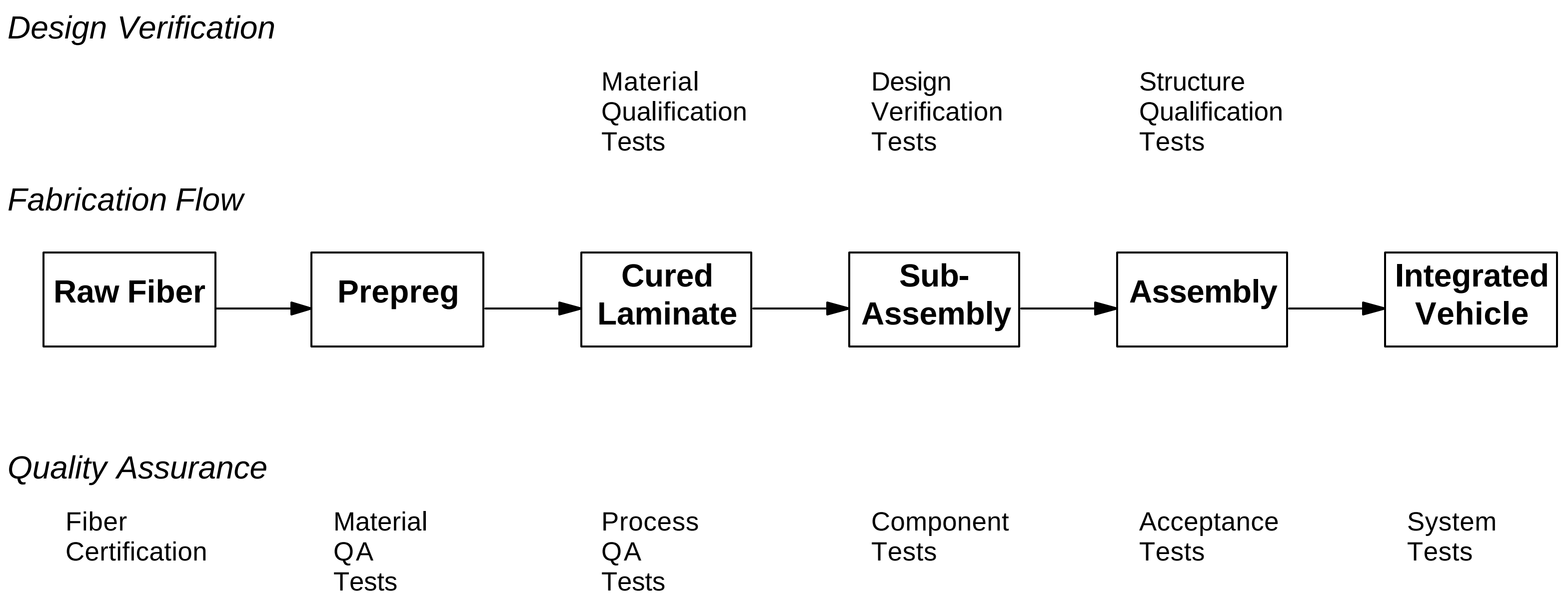
MQT = Materials Qualification Te
HCS = Honeycomb Sandwich P
IPT = Insert Pull Test
AJT = Adhesive Joint Test
BJT = Bolted Joint Test
AWT = Aluminum Weld Test
WST = Wing Static Test
FST = Fuselage Static Test
TST = Tank Static Test
CST = Control Surface Test
CSM = Control Surface Motion T
SLT = Structure Static Loads Te
CCT = Captive Carry Test

Test Sequence	Test ID	Title
Materials Qualification	MQT-1	Compression Allowable
	MQT-2	Tension Allowable
	MQT-3	In-Plane Shear Allowable
	MQT-4	Flex Strength Allowable
Honeycomb Sandwich Panel	HCS-1	Long Beam Flex
	HCS-2	Core Flatwise Tension
	HCS-3	Core/Face Peel

Test Sequence	Test ID	Title
Insert Pull	IPT-1	Pull-Out
	IPT-2	Shear Out
Bolted Joint	BJT-1	Pin Bearing Strength
	BJT-2	Bolt Pull-Out
	BJT-3	Slotted Joint Shear
	BJT-4	Open Hole Compression

Test Sequence	Test ID	Title
Adhesive Joint	AJT-1	Peel Strength
	AJT-2	Lap Shear Strength
	AJT-3	Bending / Peel Strength
Wing Static	WST-1	Pull-Up Load Case
	WST-2	Landing Load Case
	WST-3	Elevon Load Case
	WST-4	Max Torsion Load

Figure 3.10 Design Verification



3.2.6 Non-Destructive Evaluation (NDE)

NDE activities include use of audible “tap testing” and ultrasound on all composite materials including the RP-1 fuel tank. X-ray is also used to look for voids in composite fuselage panels. Traditional dye-penetrant inspection and X-ray techniques are used for all welded aluminum structures, such as the LOX tank.

3.2.8 Program Reviews and Action Response Process

Program Reviews

In concert with the “Better/Faster/Cheaper” program development concept, OSC has established a focused program review process tailored to the needs and requirements of the X-34 program. This approach provides for a minimal or reduced set of formalized reviews comprised of the following:

- System Requirements Review
- Outer Mold Line Freeze
- System Design Freeze
- System Verification Review
- Pre-Ship Review
- Pre-Launch Review(s)

The meeting that essentially kicked-off the X-34 program was the System Requirements Review (SRR) conducted in September 1996. The primary objective of this review was to establish system requirements to a level sufficient to allow a design to be formulated and provide the Government with the insight necessary to ascertain the adequacy of the contractor’s efforts in defining and allocating the system requirements. To this end the SRR defined system characteristics, identified configuration items, and established the system allocated design baseline.

An Outer Mold Line (OML) Freeze was completed in December 1996. The purpose of this review was to assure that the development of the vehicle aerodynamic configuration was sufficiently mature to allow detailed design of long lead items and construction of wind tunnel models to proceed with minimal risk. The OML Freeze did not represent a detailed systems design review.

A System Design Freeze (SDF) was conducted in May 1997. The scope of this review included a detailed status review of all system/subsystem designs, schedule performance, and all Interface Control Documents (ICD) and specifications. The SDF also reviewed the status of all action items generated at the System Requirements and OML Reviews. Formal reviews yet to be completed are the System Verification Review, Pre-Ship Review and the set of pre-launch reviews which, as currently proposed, would consist of the following to be conducted prior to each flight:

- Flight Safety Review (L-2 to L-4 weeks)
  - finalize WSMR Flight Safety Operational Plan
  - flight safety oriented
- Mission Readiness Review (TBD)
  - Vehicle preparedness
  - mission success oriented
- Flight Readiness Review (L-1day)
  - Range preparedness

<u>Action Response Process</u>

As an integral part of all formal reviews, an action item identification and response process was established and implemented. This process is principally implemented through the use of the Review Action Recommendation (RAR) document. This document contains the following elements:

- Originator (any participant i.e. Government, academic, industry, etc., who is involved in the particular review)
- Description of issue
- Principal OSC response individual or actionee
- System/subsystem/component of interest
- Recommended action and assignment criteria i.e. accept, modify, combine, close, etc.

The steps to RAR close-out are:

- Responsible Orbital actionee submits RAR status/disposition to X-34 System Engineer
- Closure is accepted/rejected by Chief Engineer and System Engineer
- Rejected RARs returned to actionee for further action
- Closed RARs logged into electronic file system
- Copies of closed RARs sent to MSFC X-34 Chief Engineer
- MSFC X-34 Chief Engineer forwards closed RAR copies to RAR originators
- Originators may request further action if Orbital response was not satisfactory

3.5 FASTRAC Engine - SMA Support

The FASTRAC 60K engine is being designed and built by MSFC and will be provided as GFE to OSC for the X-34 Program. FASTRAC was conducted in accordance with ISO 9001 requirements. Four engines will be built for testing by Stennis; the flight engines will be built and shipped to OSC. The FASTRAC 60K engine development is being implemented by product development teams (PDTs) at MSFC. MSFC SMA is supporting the development through membership on the PDTs. MSFC SMA prepared a Quality Plan for the FASTRAC engine which gives the quality requirements, based on MSFC quality system, for processing and acceptance of hardware and test verification. Along with the Quality Plan, MSFC SMA prepared an Inspection and Testing Plan for the FASTRAC engine. This document specifies the inspection and test requirements that will be required for the acceptance of FASTRAC Engine hardware. MSFC SMA prepared a Risk Management Report for the test engine. This report presents a new concept for combining hazards, failure modes and effects, and critical items into a single document. A separate Risk Management Report has been prepared for the flight engine and will be updated as required by the engine test program. These risk management reports have been/will be provided to OSC. MSFC Safety and Quality approve drawings and documentation for initial release, as well as changes as CCB members. MSFC SMA has also provided safety and quality inputs to the Engine Hot-Fire/Test Specification development and will support these tests.

3.6 Main Propulsion System (MPS) - SMA Support

MSFC, through a task agreement with OSC, is designing the MPS for the X-34 program. MSFC will design the MPS and provide the drawing/documentation package to OSC. MSFC SMA will continue to provide the necessary support for this task. This support includes quality and safety inputs to the design, review and approval for drawings and documents, and CCB membership. MSFC has also prepared a Risk Management Report for the MPS that combines hazards, failure modes, and critical items into one document.

4.4 Baseline X-34 Flight Termination System (FTS)

<u>X-34 Flight Termination System Hardware</u>

OSC has purchased the FTS receiver from Herley-Vega (HV) as recommended by the White Sands Missile Range (WSMR). HV receivers have been in use at WSMR since 1990. While this receiver has a long record of demonstrated flight success, HV uses commercial manufacturing practices where parts traceability and documentation is not a standard service. Note that the absence of parts traceability may represent an issue for the certification of the HV-FTS on the Eastern Test Range because of EWR 127-1 requirements for 100% parts traceability.

<u>X-34 Flight Termination Process</u>

The X-34 flight termination process involves two steps. The first FTS up-link command, “engine cut-off”, closes the engine valves which shuts down the propulsion system. With engine shutdown the flight computer autonomously sends commands to dump remaining fuel and oxidizer. The X-34 continues to operate under autonomous internal guidance/navigation and control software and has the opportunity (5 to 8 seconds) to correct the errant trajectory. If the vehicle fails to recover, a “terminate” command is transmitted resulting in an “energy dissipation mode”, where there is no net lift, and the vehicle assumes a ballistic trajectory. This is accomplished by a high-pressure helium system which simultaneously drives the port elevons (control surfaces) up, and the starboard elevons down.